# ENERGY EFFICIENCY OF TOOL MACHINES

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The shortage of primary energy sources, such as oil and gas, on the market has recently led to a sharp hike in energy prices in Germany, especially in 2022. Since 2019, industrial energy prices (including tax on electricity) have risen by 44% [1]. The industrial sector in Germany is facing huge challenges as a result of this drastic, comparatively rapid trend. Implementing short-term measures to save energy can therefore make a valuable contribution to companies in stabilising their economic situation.

In many companies, tool machines are some of the biggest energy consumers in machine construction, which means that they also present huge potential to save energy. However, companies often lack the knowledge and experience to evaluate this potential and to assess how any countermeasures might affect the manufacturing process. This article will highlight this particular issue using concrete numerical data from various different tool machines.

# IMPACT OF THE BASE LOAD

When considering the entire product life cycle of a tool machine, energy costs already accounted for
around 16.8% of overall costs (2019) before the rapid hike in energy prices [2]. In 2022, this value is likely to have been considerably
higher. So reducing the amount of energy that tool machines consume is not just a way for industrial manufacturing to increase its sustainability; it also helps companies take a considerable load off their finances. Operating a modern tool machine involves the use of various different main and auxiliary units. In the WZL of RWTH Aachen University, tests were carried out on a machining centre to assess the energy consumption of key units, as
shown in Fig. 1 [3]. In this example, the main spindle, which provides the necessary metal removal rates for the milling process, accounts for merely around 10% of the electric power consumption.

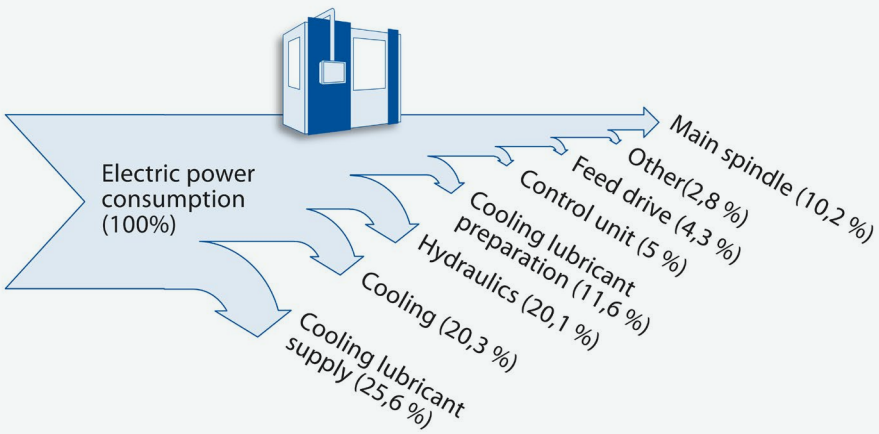



*Fig. 1: Electric power consumption of individual units of a tool machine, based on [3]*

The auxiliary units account for a major share of the power consumption, and thus the electricity consumption. While the main spindle only converts electric power into mechanical power during the machining process, most of the units are in constant operation. With activation of the main switch and powering on of the main drives, these units are operated under constant conditions regardless of requirements, which can result in a high base load. The cooling lubricant supply, active cooling systems and hydraulic units are the real energy consumers of tool machines. A machine that is switched on but is not being used can quickly become
a hidden cost driver.

Tab. 1 shows measurements of the average power consumption as well as the resulting energy costs per year for a 5-axis machining centre in the WZL for different operating modes. The specified energy prices were based on a two-shift operation across 300 days per year. If the axes of the tool machine remain switched on during the unmanned nightshirt (for thermal reasons for example), this results in annual costs of € 2,741.47. In a large machine park, the costs could quickly reach into high figures, so switching tool machines off certainly has the potential to reduce operational energy consumption.

Tab. 1: average power consumption and energy costs of a tool machine [4]

| No. | Description | Power consumption | Energy costs per year* |
|---|---|---|---|
| 1 | Machine switched on | 0.50 kW | € 320.33 |
| 2 | Machine and main drives switched on | 4.29 kW | € 2,741.47 |
| 3 | Machine, main drives and cooling lubricant switched on | 8.27 kW | € 5,290.21 |

**in the case of 26.64 ct/kWh [2], 8 h machine standstill per day and 300 operating days per year*

Switching off a tool machine on a regular basis has benefits beyond reducing energy consumption; it can have a positive impact on two other important aspects.

1 ) Thermal behaviour of tool machines

2 ) Service life of electronic components

For tool machines that have high accuracy requirements, cooling down the machine's structure too much during standstill phases can result in the required component quality not being reached during production start-up. That is the reason why some operators try to operate the machine in a constant thermal steady state. This is always a consequence of the underlying thermal boundary conditions in a stationary state. As a result, it is not possible to make a general statement about the extent to which cooling down a machine will affect working accuracy during production start-up. The thermal behaviour of two example machines in a switched-on state was therefore investigated (see Fig. 2). The graphs show clearly different thermal time constants with respect to reaching 80% of the shift to a steady state. Whereas with machine 1 (5-axis machine, low total mass) a near-steady state could be reached relatively quickly, with machine 2 (4-axis machine, large total mass), it took significantly longer due to the considerably larger thermal capacity. While for very large machines or applications with particular accuracy

requirements, switching off the system can disturb the thermal characteristics, there are also a lot of applications in which the effects of regularly switching off the system are within reasonable limits.

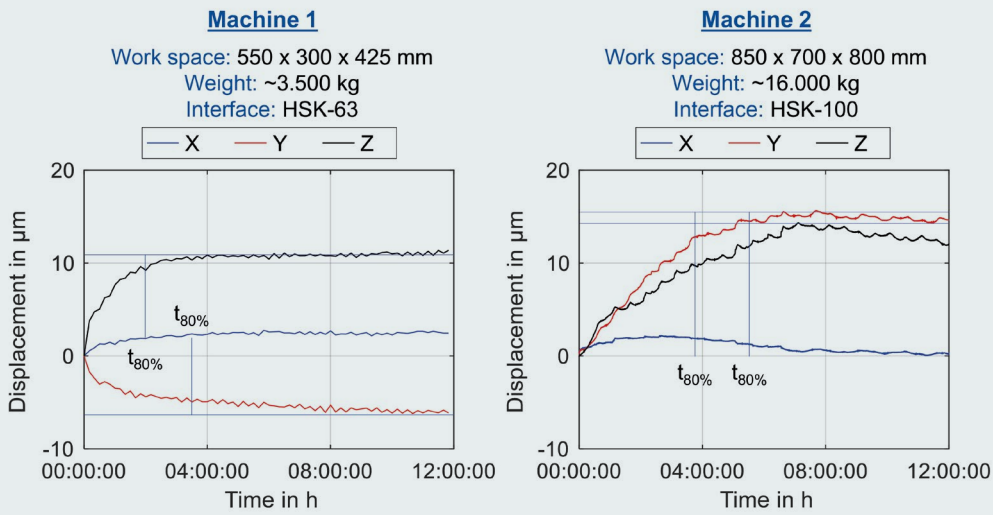



*Fig. 2: Thermo-elastic shift curve of two tool machines in a switched-on state (without axis movements) [4]*

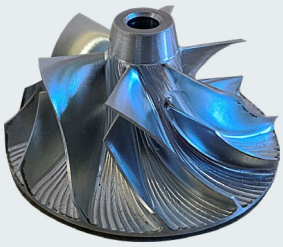
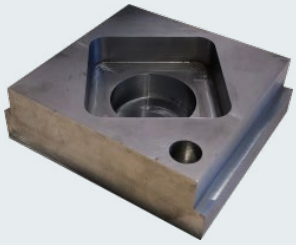
Regularly switching a machine on and off can also affect the service life of electronic components, such as semiconductor elements and capacitors. When switching on, there may be a temporary flow of switch-on currents that are several times higher than the subsequent nominal current. Commercial inverters are therefore equipped as standard with an inrush current limiter (also called a "soft starter"), enabling them to reach power switching frequencies of 120 seconds without damage.

# INFLUENCE OF PEAK LOADS

For a lot of working processes, high axis acceleration is what enables productive machining, but at the same time it requires high drive power. Steep speed profiles cause high axis currents temporarily, also called peak loads. In modern control units, the maximum acceleration of the individual machine axes can be comparatively easily modified via machine tool data. In the tests undertaken in the WZL, the effects of the peak loads on the energy consumption of a tool machine was investigated (see Fig. 2). The manufacture of two components was considered in this respect. The manufacture of component 1, an aluminium impeller, required complex 5-axis processing with a lot of different movements in the feed axes and the use of cooling lubricant. Component 2, on the other hand, was a 3-axis component made of steel. Three different acceleration levels were considered in the tests – 100%, 75% and 50%. While for component 2

the acceleration had no apparent effect on productivity and power consumption, with component 1 it was a different story. Here, reducing the axis acceleration caused a considerable increase in manufacturing time per unit. In terms of energy consumption, the outcome was quite interesting. A reduction of the peak load influence initially reduced the energy consumption per component. However, reducing the acceleration even further caused this effect to go into reverse. This can be explained by the fact that the peak load influence in this case was comparatively low. At the same time however, increasing the processing time only caused the auxiliary units to consume more power per manufactured component. Overall, peak loads resulting from high axis acceleration thus have a comparatively low influence on energy consumption. The extent to which reducing the axis acceleration might be expedient would therefore have to be assessed on a case-by-case basis.

Tab. 2: Influence of the axis acceleration on processing time and power consumption based on the e xample of two components

| | Component 1 – 5-axis | | Component 2 – 3-axis | |
|---|---|---|---|---|
| |  | |  | |
| **Axis acceleration** | | | | |
| 100% | 0.804 kWh | 3:56 min | 1.163 kWh | 13:07 min |
| 75% | 0.795 kWh | 4:03 min | 1.163 kWh | 13:07 min |
| 50% | 0.853 kWh | 4:15 min | 1.163 kWh | 13:07 min |

There are many different ways of increasing the energy efficiency of tool machines. Even just by measuring how much energy a tool machine consumes can afford greater transparency and provide a starting point for companies to make their operations more energy-efficient.
It is also important to bear in mind that any measures that increase productivity will ultimately have a positive effect on energy consumption. Any additional energy consumption of the main units is usually incommensurate with the true energy consumers: the auxiliary units.

[ 1 ] M. Dehli: Lebenszykluskosten von Maschinen und Anlagen. In: Energieeffizienz in Industrie, Dienstleistung und Gewerbe: Energietechnische Optimierungskonzepte für Unternehmen, Wiesbaden, Springer Vieweg, 2019, P. 81–95.

[ 2 ] https://de.statista.com/statistik/daten/studie/252029/umfrage/industriestrompreise-inkl-stromsteuer-in-deutschland/

[ 3 ] C. Brecher: Effizienzsteigerung von Werkzeugmaschinen durch Optimierung der Technologien zum Komponentenbetrieb – EWOTeK, Aachen, Apprimus Verlag, 2012.

[ 4 ] Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University